Course/Course Code:

Data Acquisition and Microcontroller (MC-546)

Lecture # 01

DATA ACQUISITION SYSTEM

Course Teacher:

Dr. Tariq Rehman

FUNDAMENTALS OF DATA ACQUISITION

- **Data Acquisition** is the process by which physical phenomena from the real world are transformed into electrical signals that are measured and converted into a *digital format for processing, analysis, and storage* by a computer.
- Generally, the ***data acquisition (DAQ) system*** is designed to **acquire data as well as to act on it**.
- In defining DAQ systems, the control aspects of the overall system must be considered. **Control** is the process by which digital control signals from the system hardware are convened to a signal format for use by control devices such as actuators and relays.
- A data acquisition and control system, built around the power and flexibility of the PC, may consist of a wide variety of diverse hardware building blocks from different equipment manufacturers.

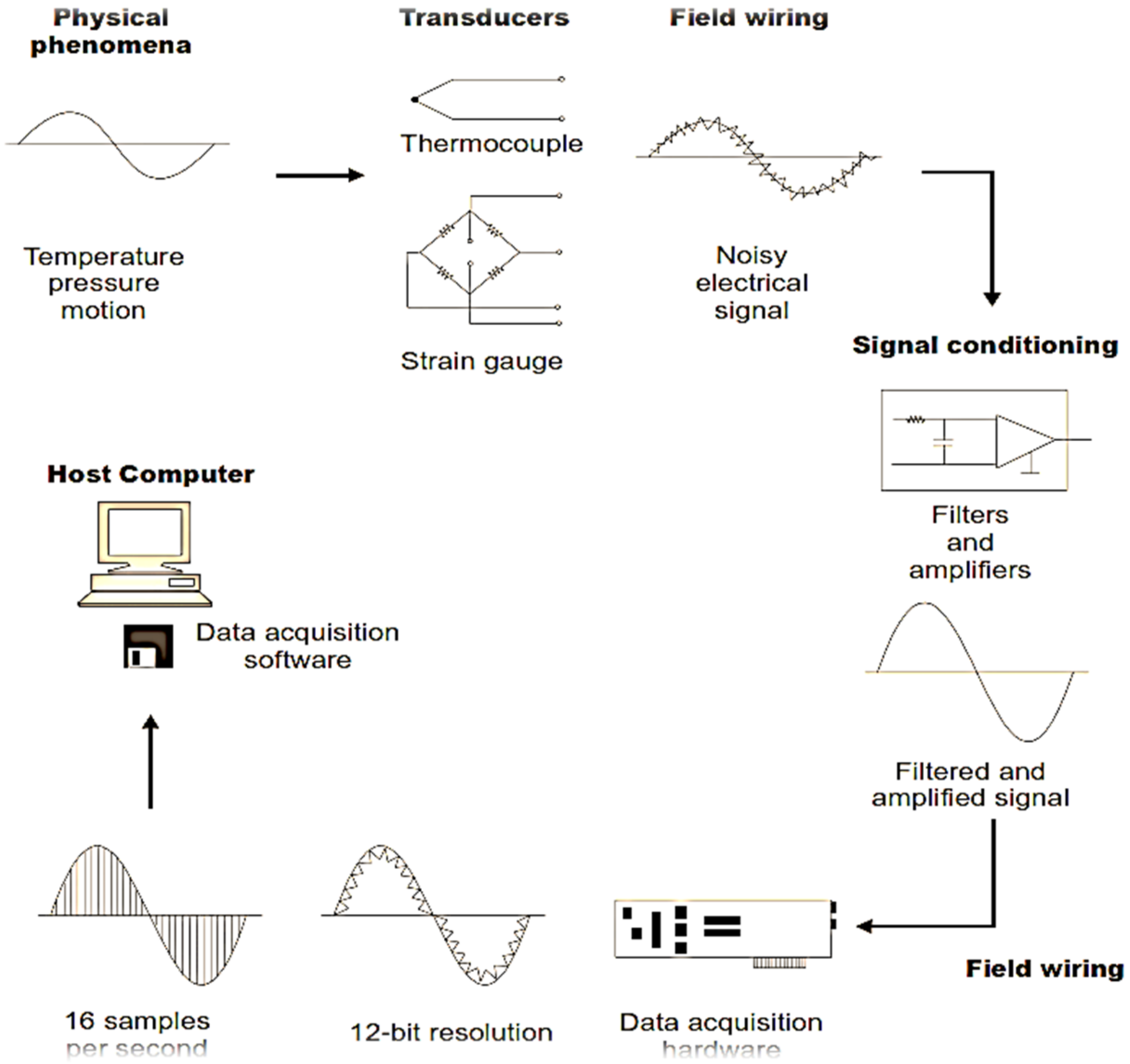
FUNDAMENTALS OF DATA ACQUISITION

☐ The basic elements of a data acquisition system, are as follows:

i. Sensors and transducers
ii. Field wiring
iii. Signal conditioning
iv. Data acquisition hardware
v. PC (operating system)
vi. Data acquisition software

☐ Each element of the total system is important for the accurate measurement and collection of data from the process or physical phenomena being monitored.

FUNCTIONAL DIAGRAM OF A PC-BASED DATA ACQUISITION SYSTEM



I. Transducers and Sensors

- **Transducers and sensors** provide the actual interface between the real world and the data acquisition system by converting physical phenomena into electrical signals that the signal conditioning and/or data acquisition hardware can accept. **For example**,

a. thermocouples, resistive temperature detectors (RTDs), thermistors, and IC sensors convert temperature into an analog signal,

b. while flow meters produce digital pulse trains whose frequency depends on the speed of flow.

c. Strain gauges and pressure transducers measure force and pressure respectively, while other types of transducers are available to measure linear and angular displacement, velocity and acceleration, light, chemical properties (e.g. CO concentration, pH), voltages, currents, resistances or pulses.

II. Field Wiring and Communications Cabling

- When the signal conditioning and/or data acquisition hardware is remotely located from the PC, then the field wiring provides the physical link between these hardware elements and the host computer.

RS-232

- If this physical link is an RS-232 or RS-485 communications interface, then this component of the field wiring is often referred to as communications cabling.
- **RS232** is full-duplex (data can be transmitted in both directions on a signal carrier at the same time, e.g. local area network), **RS485 is half-duplex**, and **RS422 is full-duplex.**
- The correct earthing and shielding of field wires and communications cabling is of paramount importance in reducing the effects of noise.

III. Signal Conditioning

- Electrical signals generated by transducers often need to be converted to a form acceptable to the data acquisition hardware, particularly the A/D converter which converts the signal data to the required digital format.
- In addition, many transducers require some form of excitation or bridge completion for proper and accurate operation.
- The principal tasks performed by signal conditioning are:
  - Filtering
  - Amplification
  - Linearization
  - Isolation
  - Excitation

III. Signal Conditioning

(a) Filtering:

- In noisy environments, it is very difficult for very small signals received from sensors such as thermocouples and strain gauges (in mV), to survive without the sensor data being compromised.
- The noise is of the same or greater order of magnitude than the required signal, the noise must first be filtered out. Signal conditioning equipment often contains low pass filters designed to eliminate high frequency noise that can lead to inaccurate data.

(b) Amplification: Having filtered the required input signal, it must be amplified to increase the resolution. The maximum resolution is obtained by amplifying the input signal so that the maximum voltage swing of the input signal equals the input range of the analog-to-digital converter (ADC), contained within the data acquisition hardware.

III. Signal Conditioning

(c) Linearization:

- Many transducers, such as thermocouples, display a non-linear relationship to the physical quantity they are required to measure. The method of linearizing these input signals varies between signal conditioning products.
- For example, in the case of thermocouples, some products match the signal conditioning hardware to the type of thermocouple, providing hardware to amplify and linearize the signal at the same time.
- A cheaper, easier, and more flexible method is provided by signal conditioning products that perform the linearization of the input signal using software.

III. Signal Conditioning

(d) Isolation: Signal conditioning equipment can also be used to provide isolation of transducer signals from the computer where there is a possibility that high voltage transients may occur within the system being monitored, either due to electrostatic discharge or electrical failure.

- Isolation protects expensive computer equipment from damage and computer operators from injury.
- In addition, where common-mode voltage levels are high or there is a need for extremely low common mode leakage current, as for medical applications, isolation allows measurements to be accurately and safely obtained.

(e) Excitation: Signal conditioning products also provide excitation for some transducers. *For example:* strain gauges, thermistors and RTDs, require external voltage or current excitation signals.

IV. Data Acquisition Hardware

- Data acquisition and control (DAQ) hardware can be defined as that component of a complete data acquisition and control system, which performs any of the following functions:
  - The input, processing and conversion to digital format, using ADCs, of analog signal data measured from a system or process – the data is then transferred to a computer for display, storage and analysis.
  - The input of digital signals, which contain information from a system or process.
  - The processing, conversion to analog format, using DACs, of digital signals from the computer – the analog control signals are used for controlling a system or process.
  - The output of digital control signals.

IV. Data Acquisition Hardware

- Data acquisition hardware is available in many forms from many different manufacturers.
- Plug-in expansion bus boards, which are plugged directly into the computer’s expansion bus, are a commonly utilized item of DAQ hardware.
- Other forms of DAQ hardware are intelligent stand-alone loggers and controllers, which can be monitored, controlled and configured from the computer via an RS-232 interface, and yet can be left to operate independently of the computer.
- Another commonly used item of DAQ hardware, especially in R&D and test environments, is the remote stand-alone instrument that can be configured and controlled by the computer, via the IEEE-488 communication interface.

V. Data Acquisition Software

- Data acquisition hardware does not work without software, because it is the software running on the computer that transforms the system into a complete data acquisition, analysis, display, and control system.
- Application software runs on the computer under an operating system that may be single-tasking (like DOS) or multitasking (like Windows, Unix, OS2), allowing more than one application to run simultaneously.
- The application software can be a full screen interactive panel, a dedicated input/output control program, a data logger, a communications handler, or a combination of all of these.

V. Data Acquisition Software

There are three options available, with regard to the software required, to program any system hardware:

1. **Program the registers** of the data acquisition hardware directly
2. **Utilize low-level driver software**, usually provided with the hardware, to develop a software application for the specific tasks required
3. **Utilize off-the-shelf application software** – this can be application software, provided with the hardware itself, which performs all the tasks required for a particular application; alternatively, third party packages such as LabVIEW and Labtech Notebook provide a graphical interface for programming the tasks required of a particular item of hardware, as well as providing tools to analyze and display the data acquired

VI. Host Computer

- The PC used in a data acquisition system can greatly affect the speeds at which data can be continuously and accurately acquired, processed, and stored for a particular application.
- Where high speed data acquisition is performed with a plug-in expansion board, the throughput provided by bus architectures, such as the PCI expansion bus, is higher than that delivered by the standard ISA or EISA expansion bus of the PC.
- Depending on the particular application, the microprocessor speed, hard disk access time, disk capacity and the types of data transfer available, can all have an impact on the speed at which the computer is able to continuously acquire data.
- All PCs, for example, are capable of programmed I/O and interrupt driven data transfers.

USB-6008 Multifunction I/O Device

- The USB-6008 is a low-cost, multifunction DAQ device.
- It offers analog I/O, digital I/O, and a 32-bit counter.
- 8 AI (12-Bit, 10 kS/s), 2 AO (150 Hz), 12 DIO USB Multifunction I/O Device.
- The USB-6008 provides basic functionality for applications such as simple data logging, portable measurements, and academic lab experiments.
- The device features a lightweight mechanical enclosure and is bus powered for easy portability.
- Can easily connect sensors and signals to the USB-6008 with screw-terminal connectivity.

Sensors and Transducers

- ☐ Transducers and sensors are used to convert a physical phenomena into an electrical signal (voltage or current) that will be then converted into a digital signal used for the next stage such as a computer, digital system, or memory board.

1. Temperature Sensors

- ☐ The most common techniques for detection of temperature are resistance temperature detectors (RTDs), thermocouples, thermistors, and sensor ICs.
- ☐ The choice of **temperature Sensors** depend on some factors such as: required temperature range, linearity, accuracy, cost, and features.
- ☐ **RTDs** are more commonly known; they are built using several different materials for the sensing element, **for example** the Platinum. Platinum is used for different reasons: high temperature rating, very stable, and very repeatable. Other materials used for RTD sensors are nickel and copper.

Sensors and Transducers

- **Thermocouple** is composed of two different metals that have a common contact point where it is produced a voltage (some mV) proportional to the variation of the temperature.
- **Thermistors** are generally composed of semiconductor materials. There are thermistors with positive and negative temperature coefficient known as PTC and NTC, respectively.
- The thermistors with negative temperature coefficient are used to monitor low temperature of the order of 10 K. The temperature coefficient is defined from the following equation:

$$\alpha(t) = \frac{1}{R(T)} \frac{\mathrm{d}R}{\mathrm{d}T} \tag{1}$$

- In general, a linear curve is used for working only over a small temperature range. For accurate temperature measurements, it is necessary to use the Steinhart–Hart equation:

Sensors and Transducers

where a, b, and c are parameters. The solution of Eq. (2) can be written as Eq.(3):

$$\frac{1}{T} = a + b * \ln(R) + c * \ln^3(R) \tag{2}$$

where,

$$R = e^{\left(x-\frac{y}{2}\right)^{\frac{1}{3}} - \left(x+\frac{y}{2}\right)^{\frac{1}{3}}} \tag{3}$$

$$x = \sqrt{\left(\frac{b}{3c}\right)^3 + \frac{y^2}{4}} \tag{4}$$

and

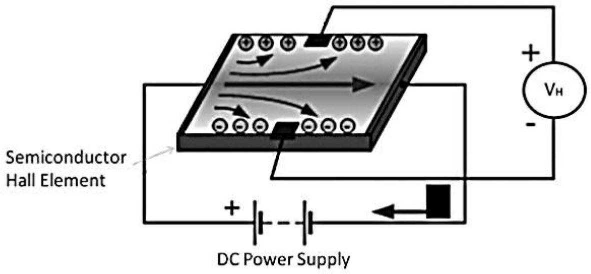
$$y = \frac{a - \frac{1}{T}}{c} \tag{5}$$

Typical values of the resistance of 3,000 Ω at room temperature (25°C) are: $a = 1.40 \times 10^{-3}, b = 2.37 \times 10^{-4}, c = 9.90 \times 10^{-8}$

Sensors and Transducers

2. Magnetic Field Sensors

- Magnetic sensors convert magnetic energy into electrical signals for processing by electronic system.
- Magnetic sensors are designed to respond to a wide range of magnetic field; they are mainly used in different applications, in particular in automotive systems for the sensing of position, distance, and speed.
- For example, the position of the car seats and seat belts for air-bag control or wheel speed detection for the anti-lock braking system (ABS).
- Magnetic sensors work according to the Hall Effect (see Fig.): the production of potential difference (Hall Voltage) across a conductor where a perpendicular magnetic field is applied.



Hall effect sensor

Sensors and Transducers

- ☐ The output voltage, called the Hall voltage, (*V*) of the basic Hall Element is directly proportional to the magnetic field (*B*) passing through the semiconductor material:

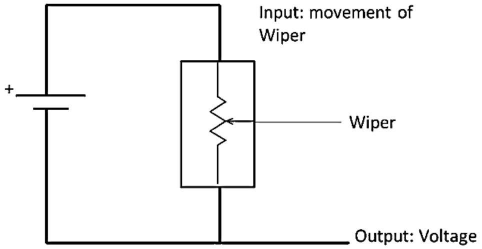
$$V_{\mathrm{H}} = R_{\mathrm{H}} * \left(\frac{I}{t} * B\right)$$

- ☐ R_H is the Hall Effect coefficient, I is the current flow through the sensor in Ampere, and t is the thickness of the sensor in mm.
- ☐ Most commercial Hall effect devices are manufactured with built-in DC amplifiers, voltage regulators to improve the sensors sensitivity, and the range of output voltage that is quite small, only few microvolts.

Sensors and Transducers

3. Potentiometers

- A potentiometer is an electromechanical device that contains a movable wiper arm with the goal of maintaining electrical contact with a resistive surface; the wiper is coupled mechanically to a movable linkage.
- It gives a voltage signal by divider circuit when voltage is applied across the entire resistance within the potentiometer (See Fig.).
- A variable potential difference can then be produced at a central wiper arm relative to one of the resistor as the wiper is moved. The wiper is usually made of a material such as beryllium.

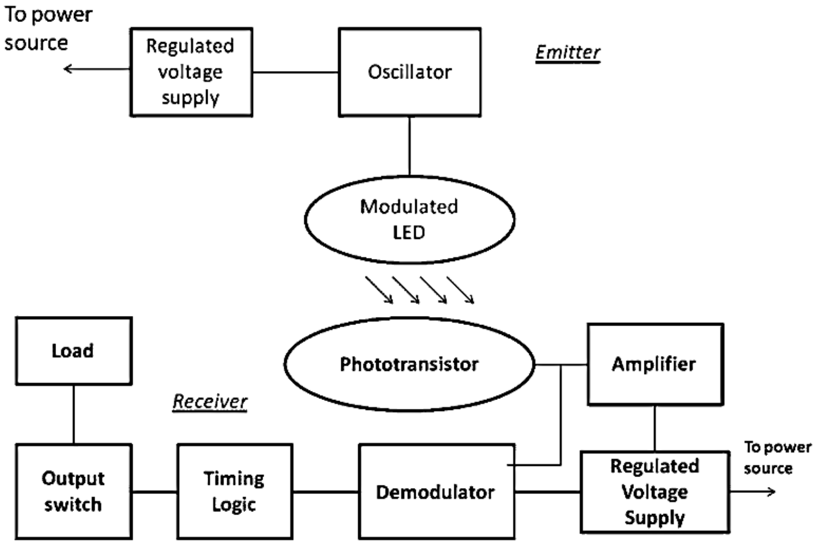


Potentiometers

Sensors and Transducers

4. Light Detection

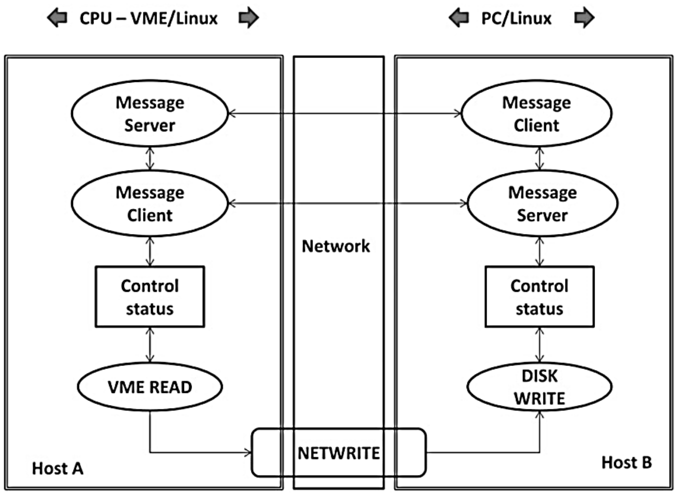
- Light sensors detect light emitted or given off from an object, such as LED, reflected from surfaces, transmitted from electronics device, and so on.
- **LED** or light emitting diode is a solid-state semiconductor that emits light when current passes through it in the forward direction.
- A photoelectric (see Fig.) sensor is an electrical device that respond to the change in the intensity of the light falling upon it.



Light detection: data acquisition system

DAQ Software

- DAQ software is the main component of the DAQ system and is needed for the DAQ hardware to work with a PC.
- DAQ software (see Fig.) can be written in a variety of languages (e.g., C language) and can be written for the particular application in design.
- Alternatively there are a number of proprietary DAQ software packages that are available, and these can be utilized (see National Instrument with Labview).
- Usually, DAQ software is composed of a text-based user interface **(TUI)** consisting in an **(ASCII)** American Standard Code for Information Interchange configuration file and a graphic user interface (**GUI**) available by means, for example, of any Web browser.



Example for software architecture of a data acquisition system via VME bus

DAQ Software

- **ASCII** is a character encoding standard for electronic communication. ASCII codes represent text in computers, telecommunications equipment, and other devices.
- Both interfaces permit DAQ management and customization without the need of recompiling the sources, thus granting full acquisition control also to inexperienced programmers.
- The configuration file is written in a high-level language (meta language) and is easily modified by the operator.
- The GUI works at a higher level with respect to the ASCII configuration file and helps the operator in compiling the configuration file and in controlling the acquisition.
- The use of the Web interface does not require any knowledge of the configuration file syntax and avoids “grammatical” errors.

Communications Cabling

- Field wiring is the physical connection from the transducers/sensors to the DAQ hardware.
- When the signal conditioning and/or DAQ hardware is remotely located from the PC, then it is necessary to use field wiring that provides the physical link.
- In this case, it is very important to estimate the effects of the external noise, especially in industrial environments.

Noise is a random fluctuation in an electrical signal generated by electronic devices. In communication systems, the noise is an undesired random disturbance of a useful information signal.

Thermal Noise or Johnson–Nyquist noise is generated by the random thermal motion of electrons. Thermal noise is approximately a white noise: the amplitude of the signal can be described by a Gaussian probability density function.

Communications Cabling

The root mean square (RMS) voltage due to thermal noise v_n, generated in a resistance R (ohms) over bandwidth Δf (hertz), is given by

$$v_n = \sqrt{4 k_{\mathrm{B}} T R \Delta f}$$

where k_B is Boltzmann’s constant (joules per kelvin) and T is the resistor’s absolute temperature (kelvin).

Shot Noise in electronic devices consists of unavoidable random statistical fluctuations of the electric current in an electrical conductor.

Flicker Noise also known as $1/f$ noise, occurs in almost all electronic devices, and results from a variety of effects, though always related to a direct current.

Parameters of a DAQ System

To properly design a DAQ system, we must know some important parameter. The goal of this section is to describe major system parameters for a better design.

1. Accuracy and Precision

- The accuracy of a measurement system is the degree of closeness of measurements of a quantity. Relative accuracy is a measure that indicates the capability of the DAQ systems to correct output codes according to its full-scale range.
- The precision of a measurement system, instead, is called reproducibility or repeatability of measurements.

2. Noise

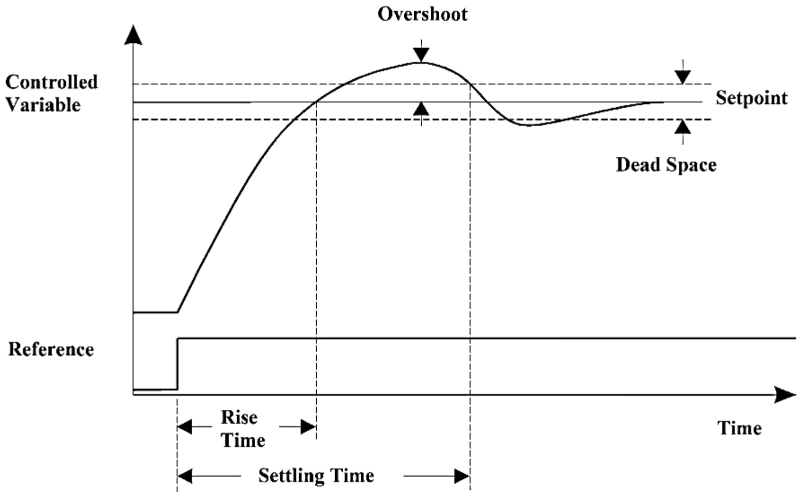
- Each measurement generates noise as combination of more signals.
- It is an interference between two terminals. One factor, common-mode noise, indicates the interferences that appear on both measurements' inputs.

Parameters of a DAQ System

- The majority of common mode interference is attributable to 50 Hz (or 60 Hz) power frequency.

3. Settling Time

- The settling time of an electronic device is the time elapsed from the application of an ideal step input to the time at which the value output has entered and remained within a specified error range.
- Parameters that can describe settling time are the propagation delay and time required to obtain output value (see Fig.).



Settling Time

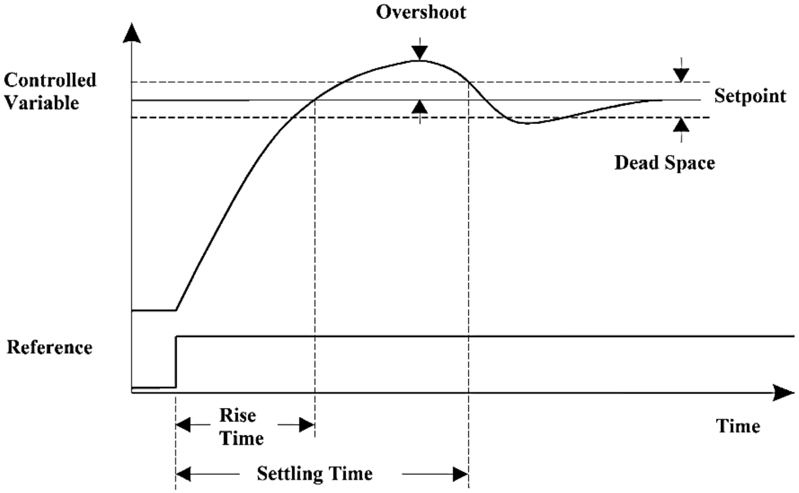
Parameters of a DAQ System

4. Acquisition Time

- Acquisition Time is a feature of the DAQ systems that indicates the presence of an analog-to-digital converter.
- It defines the time for going from one situation to a new one according to the system accuracy.

5. DC Input Characteristics

- It indicates the value of offset voltages, offset currents, and bias current of electronic devices.



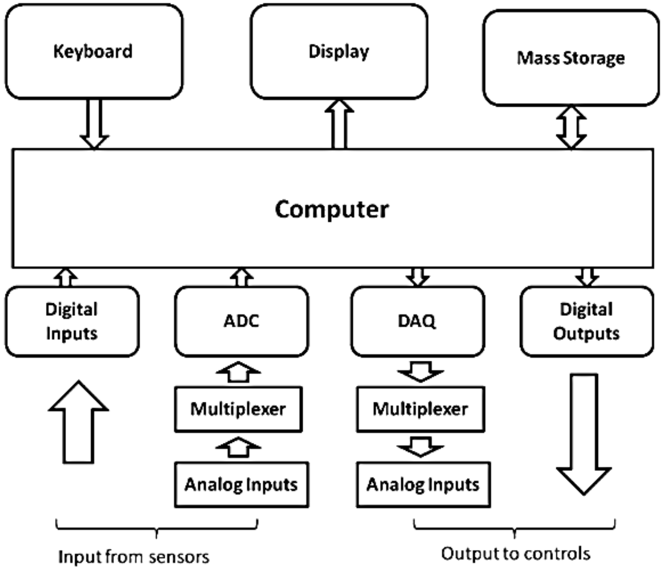
Settling time

Data Acquisition Systems: Hardware

- ☐ Capabilities and the accuracy of data acquisition (DAQ) systems can be founded from analog input specifications such as number of channels, sampling rate, resolution, and input range.
- ☐ The most common way used to transmit electrical signals over wires is the form single-ended. In general, one wire carries a voltage (the signal), while the other wire is connected to a reference voltage (ground).
- ☐ Instead, differential signal is a method of transmission of electrical signals with two complementary signals sent on a couple of wires.
- ☐ The main advantage of single-ended over differential signaling is that fewer wires are needed to transmit multiple signals. A disadvantage of single-ended signaling is that the return currents for all the signals can be shared with the same conductor, and this can sometimes cause interference ("crosstalk") between the signals.

Plug-in DAQ Systems

- Many DAQ systems, known as plug-in boards, are used in scientific application to acquire data and transfer it directly to computer memory.
- Transference of data can be done by parallel port, serial port, USB port, Ethernet port, and so on.
- Typically, DAQ plug-in boards (Fig.) are general-purpose DAQ instruments that are well suited for measuring voltage or current signals or resistance that can include some form of signal conditioning.
- Usually, application in real time of high frequency analog signals needs a high speed DAQ with a dedicated plug-in processor such as a digital signal processing (DSP) board.



Functional diagram of a basic data acquisition system

END OF LECTURE # 01

Thank you !!!